Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 104.

NOTES ON FROST.

BY

E. B. GARRIOTT,
Professor of Meteorology, Weather Bureau.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., June 15, 1899.

DEAR SIR: In compliance with directions contained in your letter of March 29, 1899, I have the honor to transmit herewith a paper on the subject of frost, prepared by Prof. E. B. Garriott, Weather Bureau, and to recommend its publication as a Farmers' Bulletin.

In an article published in 1896 in Weather Bureau Bulletin No. 86, Prof. W. H. Hammon furnished valuable information regarding methods of protection from frost which have been tested and employed in orchards, and more especially in the citrus fruit region of California.

In the autumn of 1896 the California State Board of Horticulture published a more extensive bulletin, which embodied the experiments and suggestions contained in Weather Bureau Bulletin No. 86, and treated, in an exhaustive manner, the problem of protecting California orchards from frost.

In Weather Bureau Bulletin No. 23, 1899, Professor Hammon presents a revised edition of the bulletin formerly prepared by him and submits modifications of many of his former statements which are made necessary by more recent experiments.

The methods advocated in the bulletin referred to were mainly the result of experiments conducted in California orchards, while a bulletin on frost, applicable, as far as possible, to all localities rather than to restricted districts, would doubtless be of great value to farmers, fruit growers, and gardeners; hence your direction that the Weather Bureau furnish for publication as a Farmers' Bulletin a paper on frost which shall in a popular way define frost and the conditions which favor its formation, and indicate methods of protection which have been found practicable by actual experiments. This suggestion the author has endeavored to carry out in this bulletin.

As the California experiments quoted in Bulletin No. 23 were perhaps the most thorough ever made in this country, a description of the methods employed and the results obtained are reprinted in brief in this paper, together with results of similar experiments made in the citrus fruit regions of the Gulf States, where varying climatic conditions have been found to produce somewhat different results.

Following this summary the subject of frost protection as it relates to the various other agricultural products of the country is considered, and some facts regarding freezes, which are destructive alike to tender vegetation and to plants of hardier growth, are presented.

Your wishes, as communicated in the letter referred to, that the subject be treated in a popular way and divested of all technicalities, and made applicable to all localities rather than to restricted districts, have been complied with so far as the nature of the subject will permit.

I am, very respectfully,

WILLIS L. MOORE,
Chief of Weather Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

NOTES ON FROST.

HOW FROST IS FORMED.

The atmosphere of the earth always contains more or less moisture in an invisible form. When at a considerable elevation above the earth this moisture, or aqueous vapor, is condensed, clouds are formed; when the process of condensation is more active and the temperature of the air is above freezing, rain falls; and when the temperature of the air is below freezing, snow is produced. When the moisture of the air in immediate contact with the earth is condensed at temperatures above freezing, dew is formed; when at temperatures below freezing, frost is deposited. Frost is, therefore, the moisture of the air condensed at freezing temperatures upon plants and other objects near the surface of the earth.

In the process of frost formation the temperature of the air a few feet above the earth is commonly several degrees above freezing. The surfaces upon which frost is deposited must, however, possess freezing temperatures. The manner in which frost is deposited on plants and other objects is very similar to that observed when the air moisture of a room is frozen and deposited upon window glass, the temperature of which has been reduced to freezing by the out-of-doors cold. In the case of the frost on the window glass the process is one that can readily be understood. Some explanation, however, is required of the formation of frost, which requires freezing temperature, when at times a temperature *above freezing* is registered a few feet above the surfaces upon which frost appears.

There are several processes by which the temperature of plants may be reduced below the temperature of the air which surrounds them. The most important of these processes is radiation, by means of which heat escapes from objects and passes into the surrounding air.

In the frost-forming process heat from the sun which is absorbed by the earth and by plants during the day is lost by radiation at night. During the day the earth both absorbs and reflects the heat received from the rays of the sun, and the lower stratum of air is warmed by this reflected heat. During the night when no direct heat is received from the sun's rays the lower air stratum receives no reflected heat, and, at the same time, heat which has been absorbed by the earth is radiated, or, in other words, it rises through the overlying air, though not

necessarily and entirely as sensible heat; that is, heat perceptible to the senses. In the frost-forming process there is another very important factor in the production of cold; that is, the evaporation of moisture from the earth and from plants. The nature and composition of frost require that the air in immediate contact with the surfaces upon which frost forms shall contain moisture. This is moisture that has been stored in the earth in visible form, i. e., in the form of water, and which has escaped from the earth, not as visible moisture, but by the process of evaporation and in the form of aqueous vapor. Some part of the heat stored by the earth during the day is, therefore, lost in evaporating the moisture contained in plants and in the earth. The heat utilized in this process is retained in the air, not as sensible, but as latent heat. Heat is rendered latent, in the same manner, when it is used to boil away water, and it again becomes sensible or liberated heat when the water vapor produced by boiling, which is a rapid process of evaporation, is again condensed into water. It appears, therefore, that while the temperature of surfaces upon which frost forms, and of the air in immediate contact with them, is lowered by the evaporation of moisture from the surfaces, the influence of the process does not extend to air a few feet above the ground.

Another method by which plants lose their heat is by convection, by means of which they are chilled by contact with colder air. This process, while important in the presence of freezing-air temperatures, can scarcely be considered a factor in the formation of frost proper, which is usually accomplished when temperature observations show the air to be above freezing.

Another element in the formation of frost is found in the fact that air, like fluids, arranges itself according to its density or weight. Thus the air in immediate contact with the earth becomes heavier as its temperature is lowered by the radiation of heat and settles into depressions or valleys and over lowlands, causing, at times, frost in low-lying districts, while neighboring higher grounds escape the visitations.

SEASONS OF FROST.

Generally speaking, agricultural products in some part of the United States are menaced by frost from the time nature begins to extend her mantle of green from the citrus regions of the South toward the grain fields of the North until the verdured area contracts southward before the first winds of winter; from the hour that seeds germinate and buds blossom until crops are gathered; from early spring until late fall. As a rule, the critical periods are during the early growth of plants and when the fruit is in the bloom, and again when crops are maturing. In the first instance vegetation is threatened by the frosts of early spring, and in the latter by the frosts of autumn.

Considering the several agricultural sections in greater detail we find that damaging frost is likely to occur in the north half of the Florida

peninsula and in the region immediately bordering the coast of the Gulf of Mexico, and in the Pacific Coast States from the latter part of October until the early part of April, and in the North Pacific Coast States as early as the middle of October and as late as the last week of April. From December until early in March the frost limit may, at long intervals, be extended southward well over central and even over southern Florida. The period of damaging frosts in the interior of the South Atlantic and Gulf States extends from November to April. From October to April the region in which agricultural products are subject to damage by frost is extended to the southern lake region, over the Upper Mississippi and Lower Missouri valleys, Kansas, and Nebraska, and from September to May frost visitations are usually confined to the extreme Upper Mississippi, Upper Missouri, and Red River of the North valleys, and the Rocky Mountain and plateau regions from central New Mexico and the Texas Panhandle northward. During the period, June to August, inclusive, frosts are very infrequent, and when they do occur are confined, practically, to mountain districts and to the northern tier of States.

WHEN TO EXPECT FROST.

As the conditions which produce damaging frost are subject to modifications which are as numerous as the kinds of crops raised, and as varied as local topography, local climate, and local soil conditions in the various sections of the United States, the writer in attempting to treat briefly a subject which is so diversified in its aspects is confronted with many difficulties. Suffice it to say that with other atmospheric conditions favorable for its occurrence frost may, as a rule, be expected when temperature, as reported by stations of the Weather Bureau, falls to a point 8° to 10° above the freezing point. As previously stated, the surfaces upon which frost is deposited must possess freezing temperature, although the temperature of the air a few feet above the surfaces may be several degrees above freezing; and it is the temperature of the air, in some instances many feet above the ground, that is given by the Weather Bureau observations. Another atmospheric condition favorable for the occurrence of frost is a clear, cloudless, and comparatively calm night. The presence of clouds retards radiation or loss of heat from plants; the clouds act as a screen in preventing the heat collected from the sun's rays during the day from escaping into the upper air. When clouds are not present and a withdrawal of the sun's rays causes a rapid cooling of the air at moderate elevations, the warmer air which collects near the surface of the earth during the day rises, and the cooler upper air, owing to its greater density or weight, settles to the earth. It will be noted that clouds not only prevent the escape of the warm air in immediate contact with the earth, but also blanket, as it were, the upper part of the lower air stratum. Calm or comparatively still air is a condition which favors

the formation of frost. On windy nights the air is disturbed and is not permitted to arrange itself in layers according to its density, with the densest and coldest air near the surface of the earth; it is kept mixed up by the wind.

A very interesting fact, which illustrates the manner in which cold air settles by its greater weight to the surface of the earth and allows the warmer air to assume higher levels, causing frost in low grounds and granting to the higher grounds a comparative immunity from frost, is set forth in the following article, by Prof. Cleveland Abbe, in the Monthly Weather Review for December, 1893, entitled Thermal Belts, Frostless Belts, or Verdant Zones:

These are local names given to certain regions on mountain sides within which nocturnal frost rarely or never occurs in the springtime, although freezing temperatures occur in the winter time, consequently tender vegetation flourishes with remarkable vigor in these regions. The following are the only references to thermal belts in the United States at present known to the editor, but as such regions are specially important to the horticulturist and agriculturist it is hoped that the correspondents of the Weather Bureau will bring these thermal belts to notice wherever they occur in order that their meteorological peculiarities may be better understood.

In the Agricultural Report of the Patent Office for 1861 Mr. Silas McDowell, of Franklin, Macon County, N. C., describes the verdant zone in that county in the valley of the Little Tennessee River. It occupies the region between 300 and 700 feet above the valley of the river, which latter is about 2,000 feet above sea level. On tracing this zone up among the smaller tributaries of the Tennessee River he found that in the higher valleys, where the bottom land is about 3,900 feet above sea level, the verdant zone lies between 4,000 and 4,100 feet. Within this zone frost never injures the vegetation, and the most tender grapes never fail to produce abundant crops.

Prof. J. W. Chickering, jr., in the bulletin of the Philosophical Society of Washington, March, 1883, and in the American Meteorological Journal, vol. 1, describes the following thermal belt: "In Polk County, N. C., along the eastern slope of the Tryon Mountain range, in latitude north 35, the thermal belt begins at the base of the mountain, at an elevation of 1,200 feet above the sea, and extends up 2,200 feet, being most perfect at about 1,500 feet. It is about 8 miles long, and is distinguished by magnificent flora, such as would be characteristic of a point 3 degrees south of the actual latitude."

Prof. John Leconte, of Berkley, Cal., in Science, vol. 1, p. 278, states that at Flat Rock, near Hendersonville, Henderson County, N. C., on the flank of the mountain spur adjacent to the valleys of the Blue Ridge, he also observed a frostless zone. The valley is about 2,200 feet above sea level, and the thermal belt is 200 to 300 feet above the valley.

Mr. J. W. Pike, of Vineland, N. J., states that among the mountains of California he has discovered that during the night the cold is much greater in the valleys than on the terraces several hundred feet above, due to the settling of the cold air, so that a thermal belt is formed at that height separating the frosty valleys from the colder highlands.

In the Tennessee Journal of Meteorology for January, 1894, published by the State weather service, the author describes a thermal belt between Los Angeles and the Pacific coast. It traverses the foothills of the Cahuenga range, and has an elevation of between 200 and 400 feet and a breadth of about 3 miles. It occupies the midway region of the range.

In the American Meteorological Journal, vol. 1, Mr. S. Alexander describes a thermal belt in which the peach tree flourishes in the southeastern portion of Michigan. He shows that the cold island discovered by Winchell in that region is really the bottom of a topographical depression into which the cold air settles. It is a long valley surrounded by a belt of elevated country from 50 to 600 feet above lakes Michigan and Huron. The valley and the isotherms trend northeast and southwest from Huron County through Sanilac, Lapeer, Oakland, Livingston, and Washtenaw to Hillsdale counties. The highlands of this region are all much freer from frost than the lowlands, and all much more favorable for early vegetation. He does not state that any point is high enough to be above the thermal belt, but that, in general, two equal parallel thermal belts inclose the cold island between them.

It is generally conceded that these thermal belts depend both upon the drainage of cold air downward into the lower valleys and the freedom of radiation from the surface of the ground to the clear sky overhead. During a still night, when frosts occur, the surface of the hillside cools by radiation, and hence cools the air in contact with it; the latter flows downward as long as its cooling by radiation and conduction exceeds its warming by compression. Inasmuch as its cooling depends on contact with a still colder soil or plant, it soon accumulates in the lowlands as a layer of cold air, which grows thicker during the night by the steady addition of the thin layer of descending air in contact with the ground on the hillsides. The warmer air, which has not yet had an opportunity to cool by contact with the ground, floats on top of the cold mass; it spreads out toward the hills, and is continuously furnishing its heat to the adjacent hillsides as fast as it comes in contact with them before it also cools and descends. The formation of the thermal belt seems to depend largely upon this gentle circulation during the nighttime. The lower limit of the belt is defined by the depth of the accumulation of cold air in the confined valley and rises higher in proportion as the night is clearer and longer, and also in proportion as the valley is more or less perfectly inclosed. The upper limit of the thermal belt may depend upon the strength of the wind and the general temperature of the air. But if there be no wind, then it depends equally on the freedom of radiation to the clear sky and on the above-described circulation of air.

The facts quoted in this article show that frost may be expected on low grounds at times when higher grounds escape the visitations, and the lesson they teach is that early and tender crops should, so far as may be practicable, be confined to crests, hillsides, and mountain sides, and later and hardier crops to the lowlands and valleys.

Local climate, as it is influenced and regulated by the proximity of bodies of water, must be given great weight in calculations regarding frost. Frost is less likely to occur in localities swept by moisture-laden air which has crossed a considerable body of water. This is more especially the case in the fall of the year, when the temperature of bodies of water is reduced very slowly; and in the South, where the water temperature continues relatively high throughout the year, the influence of the water is especially marked. During the colder months air is not only warmed in crossing considerable bodies of water, but it also absorbs moisture, which, although invisible in the form of water vapor, has the effect of retarding the radiation of heat from the earth. In fact, so pronounced is the influence of water and water vapor that localities which with reference to exposure to west and northwest winds are, as it were, in the lee of large bodies of water are comparatively free from frost visitations. Along parts of the east Florida

coast which are protected on the west by the Indian River, frost is said to be unknown, and throughout the central and northern sections of the United States, localities which are protected on the west and northwest by bodies of water of considerable size are not only favored, by reason of their position, with conditions which do not promote the formation of frost, but also receive the benefits derived from heavier falls of snow.

Local soil conditions constitute, to a certain extent, a factor in the formation of frost. As a rapid loss of heat is promoted by an active evaporation of moisture, it is evident that, with other conditions equal, frost is more likely to occur on damp than on dry ground, provided, however, that the ground is not too moist, for in the latter event the amount of moisture evaporated and added to the air would have a tendency to retard the radiation of heat from the earth. And herein lies the distinction, so far as frost formation is concerned, between moist air and moist soil. An excess of moisture in the air, in preventing, to a degree, the radiation of heat, is unfavorable to the formation of frost. As frost is the moisture of the air in immediate contact with the earth condensed at freezing temperature, it follows that the earth, from which the moisture of the air is drawn, must contain more or less water, and it is evident that damaging frost will occur with a limited rather than with a large quantity of moisture arising from the earth and a moderately moist and comparatively still air. Both of these conditions usually obtain following, but not too closely following, the rains of spring and autumn. The character of the soil as regards its capacity for retaining moisture must also be taken into account, more especially during periods of comparatively dry weather. Moist soil, and the vegetation which springs from it, is chilled to a lower temperature by the evaporation of moisture, and is therefore more subject to visitations of frost than soil which is dry, or into which water penetrates deeply, leaving the surface dry, or soil which sheds the rain and does not absorb and hold water. It is important to note, however, that very moist soil, or soil which contains a large amount of surface water, is, owing to the quantity of moisture yielded to the air, not so subject to the heavy and damaging frosts which visit plants on moderately damp ground or ground that has a small capacity for moisture.

PROTECTION FROM FROST.

A discussion of methods of protection from frost calls for a consideration in great detail, not only of the several approved processes of protection and the extent to which they can be applied in connection with the various crops, but also the value of these processes under the varying conditions of local topography, local climate, and local soil conditions.

It is evident, in the light of the foregoing statements, that fruit and vegetable growers in rolling and hilly country, or when located in the lee, as regards west to northwest winds, of bodies of water, can, to some

extent, so place their earlier and tenderer fruits and crops that they will, in the first instance, avoid the lowlands and valleys, and in the second take advantage of the more moderate and moist air that crosses water surfaces. For further protection the grower must depend upon artificial appliances. These appliances are designed to produce the following effects or results: To prevent a rapid radiation of heat from the earth; to charge the air with moisture; to warm the air; to create artificial drafts, whereby the air is mixed and the cold air is not allowed to settle to the surface of the earth; or to actually cover or roof in plants.

DEVICES FOR PREVENTING RAPID RADIATION OF HEAT.

Devices designed to prevent a rapid radiation of heat from the earth include screens which can be drawn over plants, vineyards, and groves; loose substances with which low plants may be covered; and smudge fires built to the windward of areas for which protection is desired. These devices, which of a necessity are operative for very limited areas, are described by Professor Hammon in Bulletin No. 23, Weather Bureau, as follows:

Glass screens.—In greenhouses and hotbeds advantage is taken of the peculiar property of glass which allows the heat rays of the sun to pass through it, and is almost impervious to the dark *heat* rays from the earth and plants. This is one of the most perfect screens possible, since it not only prevents the loss of heat by radiation, but receives and retains the heat from the sun. The expense precludes its adoption except for the protection of valuable plants and flowers.

Screens of other solid materials have been quite extensively used in protecting vineyards and citrus groves where intense cultivation is practiced and where the location of the groves near an excellent market admits of profit even with expensive methods of cultivation.

Cloth screens.—In Italy and portions of France screens made of muslin strung on wires stretched on poles above the tops of trees or vines have been used extensively. These screens are drawn on nights when frosts are probable, and are pushed back during the day. When the season has advanced so far as to preclude further danger, they are taken down and stored. Of course such a plan could be operated only on a very limited scale, and would then be expensive. This plan has been recently successfully tried in the orange groves of southern California.

Lath screens.—During the past few years screens made of laths fastened to ordinary telephone wire (the spaces between them being about the width of the laths) have been extensively used in Florida. These are spread over a frame erected above the trees or plants. The screens serve not only as a fair protection from frost, but also as a shade from the hot sun. When no longer needed, they can be rolled up and stored away for preservation. At first thought it would seem improbable that a screen covering only half the space (the spaces being as wide as the laths) would afford much protection; but when it is considered that laths have considerable thickness it is plain that while only one-half the vertical rays are screened those inclined between the vertical and horizontal are partially intercepted by the edges as well as the faces of the laths. As a matter of fact, about three-fourths of the sky is screened by this means. By placing the laths in north and south directions the direct rays of the morning sun are completely cut off from the orchard, which admits of the temperature rising slowly. This reduces the liability of injury to plants.

Other methods.—Strawberries and other low plants are frequently protected by covering them with straw or other loose substances.

Frequently young potato plants are saved by plowing a furrow alongside and allowing the dirt to bury them.

Cranberry growers in the marshes of Wisconsin flood the marshes when frost is expected. In this case the protection is probably due, for the most part, to the high specific heat of the water, as only portions of this land are submerged.

Smudge fires.—Since on cloudy nights radiation is so reduced as to prevent the formation of frost, many have thought that an artificial obscuration of the sky by means of dense smoke would be an excellent means of protection. The efforts of this character which have been made have resulted in decidedly varying success. In the wheat fields of the Dakotas excellent protection was obtained in limited areas, while the experience of orchardists in Florida and southern California has not shown such uniform success.

Since it was supposed that the protection resulted from the obscuration of the sky by means of smoke, the best protection was expected from the use of that fuel which would produce the greatest smoke.

In the Dakotas the best and most convenient material at hand was the straw of the previous year's crop, which had been left in the fields all winter and through the rainy spring, until it was quite thoroughly soaked with water.

In southern California and Florida straw was scarce, and where it could be obtained it was much drier than that used in the Dakotas. Consequently tar, crude petroleum, and other similar smudge materials were substituted; but the results have not been, as a rule, satisfactory, although the smoke was equally dense. However, quite successful results were obtained by Mr. Buck, Mr. La Rue, and others in the Vacaville and Sonoma sections by burning damp stable manure in sacks scattered throughout the orchard.

Devices for preventing a rapid radiation at night of the heat absorbed by the earth during the day can be utilized only for comparatively small areas. The screen devices, also, by reason of their cost, are available only for the smaller orchards and vineyards whose products command early market prices; the same may be said of coverings of straw and other materials for strawberries and other low plants. Smudge fires can be used to advantage for orchards, vineyards, and ground plants, and even for the smaller grain fields, and would be particularly efficacious in protecting crops and plants in low or bottom lands over which, on still nights, the smoke from smudge fires would settle. There is no device at present known that will, by preventing a rapid radiation of heat, afford any material protection to the great grain fields of the West and Northwest.

DEVICES FOR ADDING MOISTURE TO THE AIR.

Smudge fires made of damp material have been more successfully used for the purpose of affording protection from frost than those made of tar, crude petroleum, and other dry materials, for the reason that in addition to creating a dense smoke they add to the atmosphere a considerable amount of evaporated water, which, though invisible, serves to retard the radiation of heat. When any considerable amount of water is thus converted into vapor and is distributed in the air which covers the area to be protected, a portion of it is likely to be condensed by the surrounding cooler air and appear in the form of mist, which

acts as an agent to prevent the escape of heat from the earth; and the act of condensation sets free in the air some of the heat that has been expended in the process of evaporating the water contained in the smudge-fire materials. Thus the process is well ordered throughout. In the first place, an undue quantity of heat, whereby undesirable drafts would be created, is not communicated to the air by the fires, and the final result is that in reliberating, by condensation, the water in the air the particles of moisture remain suspended in the air, and some of the heat of the fires is returned to the air in a form which, to a certain degree, warms it without causing currents which would be calculated to disturb the smoke cloud, or pall, and the moist air which overlie the ground and upon whose presence the safety of the plants from frost depends.

As smudge fires made from damp materials are one of the recognized devices which have been found to be more or less effective in affording protection from frost, the following description of methods which have been adopted for utilizing them in orchards is quoted from Bulletin No. 23, already referred to:

Fires of damp straw and stable manure.—Have the fuel, in small piles, distributed throughout the orchard in advance; the more numerous the piles the better. With the same amount of fuel the best protection is obtained from small and frequent fires, since with small fires the upward draft is reduced to a minimum, and the more frequent the fires the more uniform will be the distribution of heat.

Sacks of manure.—A decidedly preferable method is to pack damp stable manure in common grain or burlap sacks, by which it can be conveniently handled. They should be distributed through the orchards in rows of about 100 feet apart and about 50 feet between sacks in each row. When it is found necessary to protect, a small amount of coal oil is poured upon each sack and ignited. It is usually unnecessary to fire more than every second or fourth sack, the remainder being left for later occasions. These sacks will burn with a smoldering fire for several hours.

The amount of heat which is set free by burning one sack of manure weighing about 50 pounds and condensing the water vapor near the earth would be sufficient to raise the temperature 20° in a space 75 feet square and 25 feet deep. If one-fourth of this heat remained within this region needing protection, which seems to be a reasonable estimate, ample protection would be obtained for almost any ordinary conditions.

Bales of wet straw.—Mr. T. A. Morrison, of Riverside, Cal., suggested the use of a similar plan, in which bales of wet straw were substituted for manure. This plan has been tried with fair success. One hundred pound bales were cut in four pieces, a tie wire being left about each piece, and if properly dampened will burn with but little care, causing a small smoldering fire.

Prunings.—The prunings of the trees, which are usually removed shortly before the period when frosts are likely to do their greatest injury, are excellent smudge material, and should always be preserved for this use. They should be piled in open spaces throughout the orchard or vineyard and burned at times when protection may be needed. The best results will be obtained from as small fires as will result in burning the prunings.

Portable smudge fires.—A number of excellent devices have been tried, in which the fires were built upon some vehicle by which they could be moved about the orchard. The advantages of this plan are several.

First. The fire can be moved to the section where most needed, which is generally along the windward side of the orchard.

Second. The loss of heat by an upward draft is almost entirely prevented, since the fire does not remain in one position long enough to establish such a draft. On this account much larger and, consequently, fewer fires, with equal efficiency, are possible.

Third. There is a much more uniform distribution of heat and smoke throughout the orchard.

As smudge fires prepared and applied in the manner above indicated are inexpensive, to a degree effective, and easy of operation, they constitute the method which for practical use and utility seems best adapted for general use in orchards, vineyards, gardens, truck farms, and small fields, as a protection from frost. Among the many devices that have been employed for holding and carrying these fires the following has been used with especially satisfactory results by the Fleming Fruit Company, of Visalia, Cal., and will doubtless prove equally effective in other sections:

> Wire frames (chicken-yard fencing) are built on low truck wagons and stretched from four wagon stakes and heaped over with wet manure. Dirt is then thrown on the wagon beds to protect them, and pots of burning tar are set underneath the straw roof. A barrel of water on the wagon is used to keep the straw wet. The wagons are driven about and do the best work, as they can go wherever the most needed. The smoke and vapor are carried to the rear as the wagon moves, and, being carried at once out of the rising heat, fall close to the ground in a long, white trail. At daylight 400 acres of orchard are covered with a white fog, extending from the ground to about 20 feet high. Similar fires are used as stationary smudges, the wire netting being stretched between four stakes driven in the ground.

Crude petroleum, supplied to a burner from a tank on a wagon or truck, has been used with success by Mr. R. H. Howard, of Riverside, Cal. Over the burner is placed a large wire basket containing mineral wool, which is kept saturated with water supplied by a tank, also placed upon the wagon. Wet straw and manure can also be used. The apparatus can be driven where most needed. The burning coal oil gives off a dense smoke, while the wet mineral wool furnishes a vast surface from which evaporation can take place, and at the same time the material will not be consumed.

DEVICES FOR CHARGING THE AIR WITH MOISTURE.

Aside from the smudge fires, Bulletin No. 23 quotes devices which have been adopted to charge the air directly with moisture, some of which are constructed on a plan too elaborate and expensive for general use.

The first operation involved is the evaporation of water in large quantities, either by means of evaporating pans or by the use of boilers with connecting pipes whereby steam can be generated, carried, and thrown into the air in different parts of a field or orchard.

Spraying and sprinkling plants in times of threatened frost has also been attended with some degree of success. At the Everest ranch,

at Riverside, Cal., sprinklers are placed at the top of 50-foot masts, which fill the air with a very fine spray. In nearly every instance the protection against frost by this method has been sufficient.

Sprinkling gardens before sunrise on frosty mornings has proved of decided value.

Secondly, irrigation, which of necessity can be used only to a very limited extent and in certain favored localities, has been found to afford very complete protection from frost in fields, orchards, and vineyards which are equipped with irrigation ditches, and in the cranberry districts of Wisconsin perfect protection from damage by frost is secured by flooding the cranberry marshes the day before heavy frost occurs in that section.

In no case should water be allowed to stand in orchards, vineyards, or gardens during the early growing period while danger from frost is possible, for the reason that water unduly promotes the growth of young plants and thereby renders them more susceptible to damage by frost and cold than are the plants whose growth is retarded.

The third operation involved in the California experiments was a direct heating of the air by means of fires. It was found that large fires caused a strong upward draft of air, which had the effect of drawing in cooler air from the sides, and that well distributed small fires were attended by very satisfactory results.

The following final report of the Riverside Horticultural Club covers the results of experiments made during the winter of 1897–98:

With the assistance of fifteen or twenty citizens interested in the study of the points involved, a most complete test has been made of the many different methods employed to prevent frost damage. With such a force of competent and impartial observers it was possible to secure data of much value in forming an estimate of the efficiency of the various plans made use of. Careful comparison was made between those orchards where no work was done, and where no direct effect of the fire was probable, and those where the different methods were being tried. As indicated by our partial report at the last meeting of the club, these tests were in some particulars eminently satisfactory as showing the way to definite conclusions.

The exceptionally long period of cold following gave additional opportunity to verify the first conclusions reached, and subsequent investigations made by ourselves, as well as by other citizens who have awakened to the possibility of protecting their property, strengthened and confirmed the opinion formed as the result of the tests already partially reported upon.

Some theories are proved to have little practical value, and members of your committee have modified their views somewhat in consequence. No preconceived notions have been allowed to stand in the way of a thoroughly practical study of the facts as they exist, to the end that the growers may not, for the lack of definite knowledge as to the directions their efforts should take, neglect reasonable precautions hereafter to insure the safety of their crops. These, however, are our conclusions:

First. There is no doubt whatever that the temperature of our orchards may be materially raised by the use of dry heat.

Second. The radiation of the earth's heat can be considerably lessened by moist smudges, when these are started early enough and are properly managed.

Third. The possibility of raising the dew point on one of the dry, cold nights peculiar to our climate sufficiently to prevent damage, by means of steam-producing apparatus, seems impracticable.

Fourth. Fruit and trees can undoubtedly be saved, even in the coldest sections, by covering them with cloth or matting, but the expense involved makes this method impossible on the part of the ordinary grower.

Fifth. It is found that the temperature in an old seedling grove, or where tall wind-breaks afford to smaller fruit trees a like protection, the temperature is almost invariably 1° to 2° higher than in exposed orchards in the immediate neighborhood. This fact seems to thoroughly upset the theory, strongly held by many intelligent growers, that the tall, well located wind-break is a disadvantage, the contrary seeming to be the truth.

Sixth. It is found that the temperature 20 feet above the ground is 1° to 2° higher than at the surface, and that, as a rule, when the cold is severe enough to injure the ripest fruit 50 feet from the ground there is almost invariably a temperature above the freezing point of water.

Professor Zumbro, who has given especial attention to this matter, finds that at the height of 50 feet the temperature is from 5° to 10° higher than at the surface when the air is not in motion. When there is any considerable breeze it varies but little.

Seventh. Our conclusion is that, all things considered, the coal baskets, sufficiently numerous, will prove the most satisfactory and effective means of warming the orchards yet made use of. It is true the oil pots make a far hotter fire, and are neither expensive nor difficult to manage; but the deposit of lamp black upon tree and fruit resulting from their use condemns this system for general use.

As to the value of smudging the members of your committee are not so well agreed. Because of less sharply defined results, we find it more difficult to come to definite, at least uniform, conclusions. But, under certain conditions, we are convinced that, properly used, it may be made a valuable means of protection. We think this especially true in localities where the temperature falls only a little below the danger point, and where there are considerable solid areas of young orchards exposed. Here it will work well if the protection is made general. But where the danger is considerable we think it wise to be prepared to use dry heat, even where in connection with the smudge. The benefit from smudging is probably as much from its protecting fruit and trees from the sudden rays of the morning sun after a freezing night as from modifying temperature during the time of danger.

Experience demonstrates that flooding or running water in connection with dry heat or smudging is a valuable adjunct. One of the committee who has been testing this matter carefully for three years is disposed to think that the direct benefit from running water is overestimated by a majority of growers. Its value in putting orchards in condition to withstand quite severe weather safely is questioned, but the committee are inclined to think that entire dependence upon this method will occasionally result in serious loss to those who trust to this means alone, especially when used in young orchards.

As to the number of baskets needed when coal is used, we find that the most decided and satisfactory results have been gained where from twenty to fifty coal fires have been used to each acre. If intelligently and energetically used this plan will never fail, except when the mercury drops below 24° for a long while, and even then it is believed the larger portion of the crop may be saved if anything like a general use of such fires be secured. The smaller number of fires named has, in numerous instances, and even when a man was working alone, secured a rise of from 3° to 5°, and saved a crop. Can it be doubted that 50 fires per acre, used in every orchard, would save both trees and crop on the coolest night ever known in California's history?

To equip an orchard with 50 baskets to the acre means an outlay of only a little over $5. The fuel to run them one night costs from $2.50 to $3. If a crop of navels upon it is worth $400 it will pay well to spend in labor and fuel $4 per night, or 1 per cent on the value of the crop to insure its safety. In the orange region of southern California it is not unusual to have more than two or three nights in a season when the fruit is in danger. But even if, as in the present season, the period of cold is more extended will it not pay to expend at least as much as one pays for his irrigating water to insure the safe maturing of a crop it has cost him a year's labor and heavy expense to produce? The conclusion is obvious that we have only to provide for the insurance of this sort of property exactly as we would in the case of that liable to destruction by fire, to be enabled to follow the business of orange and lemon growing with the certainty of having perfect fruit to market at the season's end.

While the practicability of protecting our orchards from frost seems established, the problem of the most economical and scientific means of accomplishing this is probably yet to be solved. However well the wire baskets may serve us now, there will doubtless be improved methods for burning coal, and even other material may be found that will serve the purpose better; and while wet straw seems to be at present the most available for smudges, doubtless, when the need is made known, chemists will find some vapor-producing material more compact, efficient, and economical. Hence we recommend that the club appoint a permanent committee to continue these investigations.

GENERAL OBSERVATIONS AND PRACTICAL RESULTS.

WORK IN TEXAS.

In a paper read before the annual meeting of the Texas Farmers' Congress and Texas State Horticultural Society in joint session at College Station, Tex., July 26, 1899, Mr. Joseph L. Cline, observer, Weather Bureau, submitted the following remarks on "The use of frost and temperature warnings in protecting fruits and truck gardens:"

It has been proved that a good way for protecting berry crops is to cover with hay. Berries are improved by mulching. Prairie hay used for this purpose can be cut and placed in the fields, ready for covering the plants when frost is indicated, at a cost of about one dollar a ton. Ten tons per acre are considered sufficient for protection against any freeze. The cost of labor for covering the plants would be about two dollars an acre additional. As the hay is required for mulching, the cost is considerably lessened when the hay is utilized for that purpope. Berry crops which were covered prior to the freeze of last February yielded four times as much as unprotected plants, and unprotected plants were generally killed. Cabbage, potatoes, and other vegetables can be protected from frost by hay, and the increased yield will more than pay for the expense involved. Rice growers along the east Texas coast can raise vegetables throughout the winter on their rice plantations by protecting them from frost. The plantations can easily be flooded during freezing weather, which is always of short duration, and the water would protect and do very little or no damage to the vegetables, which are remunerative during the winter season.

* * * * * * *

The method of burning stakes soaked in petroleum or kerosene oil throughout the fields can be applied not only to the protection of maize, but fruit orchards as well. By means of burning stakes fields will be enshrouded, when the wind is light, in a continuous cloud of smoke. This will, in many instances, prevent frost from occurring. The stakes must not be set so close to the fruit trees that the heat will affect the branches.

* * * * * * *

In France frost bells are sounded when frost is expected, and grape growers protect their crops by pouring tar on the ground among the vines and setting it on fire. The smoke thus made often saves the crop of an entire vineyard. Bituminous coal burned in baskets is less expensive and has been successfully used. Forty to fifty baskets of coal per acre are required, and the more used the better would be the result. Strawberry crops can be protected in this manner at a cost of $4 to $6 an acre.

* * * * * * *

The following letter from Capt. B. F. Johnson, president Gulf Coast Horticultural Association, gives an idea as to what can be done in protecting crops [by showing what was done in February, 1899]:

"I was in Galveston, Tex., on the morning of February 11, 1899, and upon hearing that a freeze was expected I called at the United States Weather Bureau office, and was informed that the hardest freeze of the season was threatened. I immediately gave orders over the long-distance telephone to my employees at Arcadia to cover up all hotbeds and also all plants already transplanted. All the plants in hotbeds were carried through the freeze by protection and saved from injury. I had about 7,500 cabbage plants set out, and on account of my employees not going to work as directed we did not reach these until ice had formed over some of the plants. I took the first train out of Galveston, which was in the afternoon, and upon my arrival at Arcadia we continued protection, notwithstanding the fact that ice had already formed over the plants. We placed a handful of hay over the north side of about 1,000 cabbage, and at least 750 of these came through the freeze uninjured, while all

the unprotected were killed. The varieties protected were the Jersey-Wakefield and Henderson-Succession, and I could see no difference between the two after the freeze. Had my employees carried out the instructions given them in the morning I would have saved 75 per cent of the 6,500 unprotected plants which were killed, and this would have yielded me about $150 net. I had 1¾ acres of Irish potatoes planted in January, which were up to fair stand. These were not protected and were all killed. I had about one-sixteenth acre planted with hand planters the 1st of February. These were protected with vines from old sweet potatoes grown on the ground the previous year. Fully one-eighth of these came up after the freeze with this light protection, and thus enabled me to put the first potatoes on the Texas market, and they brought me $3 a bushel net. If I had been prepared and protected the 1¾ acres planted in January I would have received a nice little sum, and more than ten times the cost of protection. Strawberries not mulched were virtually killed, while those mulched made an average crop. The great value of protection to berries in case of freezing weather has been forcibly illustrated. The entire crop of early berries (the only berry crop which pays well) would have been a total failure without protection."

* * * * * * *

The following communication of Mr. M. M. Cox, president of the League City Truck Growers' and Farmers' Association, League City, Tex., gives further the manner and value of protecting crops from the frost and freeze during the abnormally cold weather of February 12 and 13, 1899. Mr. Cox says:

"I had two acres of strawberries—Noonan and Mitchell varieties—which were blooming and fruiting nicely. In anticipation of a freeze we placed hay for mulching purposes between the rows, which were about 3 feet apart. Upon the receipt of the telegram, Saturday morning, February 11, 1899, announcing the approach of a freeze, I got word to the man who had charge of my berry crop. He immediately went to covering the vines with hay previously placed in the berry patch, and succeeded in covering 20 rows. The vines of the protected berries were practically uninjured, while the unprotected plants were frozen to the ground and many of them totally killed. From these 20 rows, about one-fourth acre of protected plants, we picked berries nearly three weeks before the unprotected berries were ready for market. The one-fourth acre of protected berries yielded me more than the remaining 1¾ acres altogether. In fact, we got the bulk of our crop—a little more than $300 net—off this one-fourth acre. If we had used more hay for covering we could have saved the blooms and berries already on the vines notwithstanding the severity of the freeze, as some berries were saved as it was.

"Others in League City protected berry crops with the same results as those which attended our protection.

"Hotbeds protected for ordinary freezes were killed, but some put extra covering on the beds, using blankets, and thus saved their plants without injury. Those who protected in this manner were setting their plants in the field while others were sowing seeds in the hotbeds, and were thus at least four weeks ahead with their crops for the market.

"The warnings of the Weather Service promise much for the coast country."

Mrs. C. W. Benson, Alvin, Tex., in writing of protection of crops, says:

"In past seasons the advance notices of frost and freezing weather given out by the United States Weather Bureau have been distributed among the truck growers by messenger service, and by this means have saved our planters who protect their crops thousands of dollars.

In 1899 all crops were carried through safe until the severe freeze of February 11, and in several instances tender crops were successfully protected and carried through this freeze even when the mercury stood at 4 degrees above zero or 28 degrees below the freezing point. The principal crops protected were tomatoes, cucumbers, cabbage, and strawberries. The three first mentioned were still in hotbeds or cold frames, and were protected by covering with hay to a depth of about 1 foot, over glass or

canvas. Berries were protected by turning over mulch and covering up plants from 4 to 6 inches in depth. This mulch had already been placed between the rows to retain moisture and keep the berries clean on plants. This protection did not save blooms, but the plants so protected came through the freeze with much less damage and produced more fruit than the unprotected plants. I judge that the protection was fully worth $30 per acre, as prices of berries remained firm all through the season on account of general scarcity of fruit. About 25 acres were thus protected from the freeze.

"The value of the tomato crop saved through protection from this freeze averaged fully $125 per acre in spite of the subsequent drought, which extended from February 14 until after the crop was marketed, with the exception of a few slight showers, which were insufficient for general growth of plants. With rain as in an average season the crop would have paid $250 per acre, and enough plants were carried through this freeze by protection to set 17 acres.

"About 200,000 cabbage plants were carried through this severe freeze of February and successfully transplanted. These would have netted the growers $8,000 with sufficient rain during the growing period. The value of the cucumber crop from actual results was about $1,000, which would have increased 1,000 per cent in an ordinary season, but they were held back for lack of moisture until the north Texas crop was on the market, as cucumbers which sold at from 40 to 50 cents per one-third bushel box would have netted from 75 cents to $1.25 per dozen.

"Protection of crops enables the grower to generally reach the first markets, but without the advance notices of frost and freezing weather it would be impracticable to protect; our people would bear the expense of the warnings rather than do without them."

WORK IN LOUISIANA AND FLORIDA.

Probably the most extensive experiments for the protection of citrus fruits in the Southern States have been conducted in a large orange orchard near Diamond, La., under the management of Mr. Hewitt Chapman. In the Report of the Louisiana Section of the Climate and Crop Service of the Weather Bureau for February, 1899, this grove and some of the methods employed to protect its crop are described by Mr. Alexander G. McAdie, of the Weather Bureau, as follows:

The orange orchard is about 43 miles south of New Orleans, near the river, and about 20 miles north of what is considered the safe orange belt of Louisiana. The grove covers 130 acres and contains 15,000 trees, including Creole Sweets, Mandarins, and Satsumas; sweets budded on Trifoliata and Pomeloes on sour stock. These young trees withstood the frosts of January 1, December 4, 9, 10, 11, 1898. The writer visited this grove on December 11, when ice one-quarter inch in thickness could be found along the roads and in exposed places. The orchard is irrigated by means of river water carried over the levee by a Knowles direct-acting pump, 6 by 8, worked by a 40-horsepower boiler. The pump dispenses with belt, pulley, and engine. To flood the whole orchard of 50 acres to a depth of 1 inch would require 5,650 tons of water, or 1,357,700 gallons. Barely one-hundredth part of this quantity of water is required. The water pumped from the river over the levee goes into a main ditch, from which run subditches, each subditch feeding two small inlets through the orchard between each line of trees. The distance between the trees averages 12 feet. The middle ground is cultivated and level so that the water can run in a steady stream to and out through the quarter drain into the drainage ditches which are 1 acre apart, running parallel into the rear canal.

The grove has a northern exposure; fronts on the river; the land runs west and east, falling slightly from the river; and there are no wind breaks. It is also proposed at this orchard to experiment with the various types of smudges. One portion, about 10 acres in extent, will be protected by smudge fires, some portable and

some stationary. In another section, covering about 30 acres, the bodies and lower portions of the orange trees are to be wrapped with native hay. In the third section the dirt is to be hilled up about the trees; while in the fourth the trees are to be wrapped with floor matting.

In the methods described above for the protection of trees it was thought that colder weather than that of February, 1895, was not likely to occur again. It appears that the pumping plant, on which great reliance was placed, did successfully hold back the trees up to about February 2, 1899, but the extremely warm weather of the 3d, 4th, and 5th started the sap and forced growth. It is doubtful, however, whether water protection is adequate under such severe tests. All the orange trees above ground appear to have suffered badly, in nearly every case the tree being killed. Those trees which were wrapped with matting likewise suffered and the protection again appears to have been inadequate to withstand such extreme cold. In the section where the earth was hilled up around the trees the results were very satisfactory. It is thought that about 4,000 trees have been saved by this means. An inspection of the orchard as late as March 5 indicates that notwithstanding the severity of the test, there is reason to believe that orange trees can be protected successfully by hilling up the earth.

The devices employed in Louisiana, as described above, were found to be an effective protection against damage by frost, and the protection afforded by irrigation and by wrapping the bodies and lower portions of trees with hay was sufficient for ordinary freezes. During the unprecedented cold of February, 1899, the section in which dirt was hilled up about the trees was the only one in which trees escaped serious injury.

The devices for protection from frost used in Florida conform in character to those tested in the California experiments, in which coal fires were found to be the most effective means of protection, and appliances for adding moisture to the air were successful only to a degree. As artificial appliances are totally inadequate to add to the atmosphere any very appreciable amount of moisture, it is evident that methods which may have been found ineffective in the dry climate of California would possess value in locations where their office is confined to adding moisture to an already moist atmosphere. The Gulf and South Atlantic Coast States, and in fact the country generally from the Mississippi Valley to the Atlantic seaboard possesses a moist atmosphere, and the fruits and tender garden vegetables of these districts can, therefore, be the more readily protected from frost by devices which add moisture to the air. As a means of adding moisture to the air, irrigation should be more effective than in California, and in localities where this method can be used, protection would be assured except against hard freezes.

Owing to the comparatively inexpensive character of the materials used in damp smudge fires, they seem the best adapted for common use in orchards, vineyards, and gardens. Berries and other low plants can be protected with but little expense by coverings of straw and other light materials. Devices for actually heating the free and open air are expensive and of doubtful utility, and their value is dependent solely upon a comparatively still air and small, numerous, and well-distributed fires.

In Florida many experiments have been made with a view to adopting devices which will protect orange trees from injury during the periods of severe cold which at times visit that section. The fact that these periods of cold are infrequent does not relieve the grower from the necessity of providing for their occurrence. The most economic of the devices tested appears to be the "banking up" of trees with dirt or sand. In Florida, as in Louisiana, this has been found to be a very effective means of protection. The trunks of the older trees can be banked, and the younger trees can be almost entirely covered without necessarily causing any damage to the trees.

The more expensive methods include warming the air by means of open wood fires and sheet-iron stoves. These methods have been found to be fairly satisfactory on still nights. Coverings of cloth and other suitable materials are stretched on frames and the confined air is warmed by means of stoves. One extensive orange grower is building board sheds over his groves, the interiors of which will be heated by wood fires. When danger from frosts and freezes is past, the tops and sides of the sheds can be removed. On account of their great cost, coverings of this character can not, of course, be generally used.

FROST SEASONS FOR SEVERAL CROPS.

Damaging frost is likely to occur in Florida from the middle of October until nearly the middle of April. During this period pineapples which are not in the lee of bodies of water should be afforded means of protection. Strawberries are subject to damage from January to the early part of April; oranges from December to the middle of February, and orange trees are subject to damage by freezes during December, January, and February. Garden truck is especially subject to injury from January 1 to April 15. In the trucking districts of the interior of the Gulf and South Atlantic States the period during which damaging frost is likely to occur extends from October to April, inclusive.

Temperature conditions are of great importance in the culture of rice, and a severe frost late in October may injure the grain so much as to cause its discoloration. Owing to the manner of growth and culture of this crop and the character and extent of the fields it covers, practically nothing can be done to avert injury from heavy frosts that may occur about the time of harvest.

Tobacco growers may protect their plant beds by coverings, but during the critical periods following transplanting and approaching harvest severe frost will ruin plants in fields which are too large for the successful application of the devices herein described. During the maturing season tobacco plants in large fields can be given protection from damage by frost only by cutting and "frost heaping" on the eve of the occurrence of frost.

Cotton will be seriously injured by low temperature early in the spring whether frost occurs or not. Owing to the area covered by the

fields, no adequate means of protection against cold and frost, suitable for general use, has been discovered.

In Louisiana sugar cane is planted in the fall, winter, and early spring. The plants are often killed or seriously injured by frosts in the spring and in October and November. When frost is expected, the cane can be cut close to the ground and "mattressed," the product of three rows being so laid together that the leaves of one armful will cover the butts of the preceding; being thus thatched the canes are protected from frost and will keep in this state for several weeks without injury.

In the cranberry districts of New Jersey, Cape Cod, and Wisconsin, and in limited areas in other parts of southeastern New England, and the upper lake districts, which are devoted to cranberry raising, flooding is the only effective means of protection against damage by frost. This crop is confined to swamp or bog lands, and when danger from frost is apprehended, appliances for letting in a sufficient quantity of water to keep comparatively warm and moist the lower stratum of air are usually provided.

Young potato plants can be saved from damage by frost by a covering of dirt. In large patches this can be accomplished by plowing a furrow alongside the rows of plants and allowing the dirt to bury them.

Gardens can be protected from frost by coverings of straw, paper, or other loose and light materials, or by damp smudges; and the latter device appears to be, in point of effectiveness and cost, the best adapted for general use not only for small areas devoted to gardens, but also for orchards, vineyards, and fields. The effectiveness of any method of protection is of course decreased as the area for which protection is desired is increased, and there is no process yet devised that can give adequate protection against frost and cold in the great grain fields of the country.

CONCLUSIONS.

Experiments and observation seem to establish the following facts: The danger of damage from frost can be materially lessened by placing early and tender plants on high grounds and crests, and hardier plants in low grounds and hollows. When ground can be selected in the lee, or to the south and east of considerable bodies of water, the danger will be further lessened.

In the dry climate of the citrus fruit region of California and in the promising fruit districts of Arizona small and numerous fires, preferably of coal burned in iron baskets, have been found to be the most effective device used for protection against frost; second in point of utility may be placed irrigation; and the practicable process which affords the least protection in that district appears to have been smudge fires. As before stated, the unsatisfactory character of the experiments made with smudge fires may be attributed to the fact that artificial devices are inadequate to charge dry air with sufficient moisture to prevent loss of heat from the earth by radiation. Reports of California

experiments do not distinguish between frosts and freezes. Owing, however, to the usually moderate character of the cold periods of that section the devices referred to would doubtless be equally effective against frosts and freezes.

In the orange-growing districts of the South irrigation affords the most effective protection against frost, while in sections where this process can not be employed damp smudge fires properly handled are best adapted to general use. Severe freezes which kill or injure the trees can be guarded against only by housing the trees and heating the confined air, or by "banking up" the trees with dirt or sand. The latter method is comparatively inexpensive and is therefore the better adapted to general use.

In all sections loose coverings may be used to advantage for protecting low plants, and damp smudge fires may be profitably employed in gardens, orchards, and small fields.

It is important to remark in this connection that none of the artificial devices described should be employed during the growing season except on the immediate eve of threatened frost. The necessity for observing this precaution becomes apparent when the fact is considered that any appliance for protecting plants from cold will maintain abnormally high temperatures when average weather conditions prevail. The effect of this process would be to force the growth of the plants and render them the more susceptible to damage by the late frosts of spring. In all sections and localities reached by the forecasts and special warnings of the Weather Bureau action to put into operation protective measures can be safely deferred until warning notices are issued. The Bureau has made provision for a distribution of frost warnings which is limited only by the resources of the telegraph, telephone, mail, train, and signal services, and agriculturists whose location renders possible the receipt of the warnings by any of the means referred to should adopt measures for securing them. That action in this direction would be profitable is shown by the testimony of those who have received substantial benefits from the warnings.

FARMERS' BULLETINS.

These bulletins are sent free of charge to any address upon application to the Secretary of Agriculture, Washington, D. C. Only the following are available for distribution:

No. 16. Leguminous Plants for Green Manuring and for Feeding. No. 19. Important Insecticides: Directions for their Preparation and Use. No. 21. Barnyard Manure. No. 22. Feeding Farm Animals. No. 23. Foods: Nutritive Value and Cost. No. 24. Hog Cholera and Swine Plague. No. 25. Peanuts: Culture and Uses. No. 26. Sweet Potatoes: Culture and Uses. No. 27. Flax for Seed and Fiber. No. 28. Weeds; and How to Kill Them. No. 29. Souring of Milk and Other Changes in Milk Products. No. 30. Grape Diseases on the Pacific Coast. No. 31. Alfalfa, or Lucern. No. 32. Silos and Silage. No. 33. Peach Growing for Market. No. 34. Meats: Composition and Cooking. No. 35. Potato Culture. No. 36. Cotton Seed and Its Products. No. 37. Kafir Corn: Characteristics, Culture, and Uses. No. 38. Spraying for Fruit Diseases. No. 39. Onion Culture. No. 40. Farm Drainage. No. 41. Fowls: Care and Feeding. No. 42. Facts About Milk. No. 43. Sewage Disposal on the Farm. No. 44. Commercial Fertilizers. No. 45. Some Insects Injurious to Stored Grain. No. 46. Irrigation in Humid Climates. No. 47. Insects Affecting the Cotton Plant. No. 48. The Manuring of Cotton. No. 49. Sheep Feeding. No. 50. Sorghum as a Forage Crop. No. 51. Standard Varieties of Chickens. No. 52. The Sugar Beet. No. 53. How to Grow Mushrooms. No. 54. Some Common Birds in Their Relation to Agriculture. No. 55. The Dairy Herd: Its Formation and Management. No. 56. Experiment Station Work—I. No. 57. Butter Making on the Farm. No. 58. The Soy Bean as a Forage Crop. No. 59. Bee Keeping. No. 60. Methods of Curing Tobacco. No. 61. Asparagus Culture. No. 62. Marketing Farm Produce. No. 63. Care of Milk on the Farm. No. 64. Ducks and Geese. No. 65. Experiment Station Work—II. No. 66. Meadows and Pastures. No. 67. Forestry for Farmers. No. 68. The Black Rot of the Cabbage. No. 69. Experiment Station Work—III. No. 70. The Principal Insect Enemies of the Grape. No. 71. Some Essentials of Beef Production. No. 72. Cattle Ranges of the Southwest. No. 73. Experiment Station Work—IV. No. 74. Milk as Food. No. 75. The Grain Smuts. No. 76. Tomato Growing. No. 77. The Liming of Soils. No. 78. Experiment Station Work—V. No. 79. Experiment Station Work—VI. No. 80. The Peach Twig-borer—an Important Enemy of Stone Fruits. No. 81. Corn Culture in the South. No. 82. The Culture of Tobacco. No. 83. Tobacco Soils. No. 84. Experiment Station Work—VII. No. 85. Fish as Food. No. 86. Thirty Poisonous Plants. No. 87. Experiment Station Work—VIII. No. 88. Alkali Lands. No. 89. Cowpeas. No. 90. The Manufacture of Sorghum Sirup. No. 91. Potato Diseases and Their Treatment. No. 92. Experiment Station Work—IX. No. 93. Sugar as Food. No. 94. The Vegetable Garden. No. 95. Good Roads for Farmers. No. 96. Raising Sheep for Mutton. No. 97. Experiment Station Work—X. No. 98. Suggestions to Southern Farmers. No. 99. Common Insects on Shade Trees. No. 100. Hog Raising in the South. No. 101. Millets. No. 102. Southern Forage Plants. No. 103. Experiment Station Work—XI. (In press.)